NASA TN D-405

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TECHNICAL NOTE
D-405

INVESTIGATION OF TANDEM-WHEEL AND AIR-JET ARRANGEMENTS

FOR IMPROVING BRAKING FRICTION ON WET SURFACES

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON June 1960

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INVESTIGATION OF TANDEM-WHEEL AND AIR-JET ARRANGEMENTS FOR IMPROVING BRAKING FRICTION ON WET SURFACES

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SUMMARY

In an attempt to improve tire braking characteristics on wet surfaces at high speeds, preliminary tests were made on a tire treadmill to determine the effectiveness of two methods of clearing away water ahead of a braking wheel. One method consisted of mounting a free-rolling or idling wheel ahead of a braking wheel, and the other method consisted of directing an air jet on the water-covered surface ahead of a braking wheel. Tests were made with smooth and diamond-treaded 3.00 × 7 tires (about 12 inches in diameter) on the braking wheel and a smooth 3.00 × 7 tire on the idling wheel. In the blowing tests, two nozzles having different diameters were used with air-jet pressures up to about 100 pounds per square inch. Measurements of tire friction coefficients were made with 0.09 inch of water on the belt of the treadmill over a range of speeds from 26 to 93 feet per second.

INTRODUCTION

Several investigations (refs. 1 to 4) have been made by the National Aeronautics and Space Administration to determine the braking friction characteristics of tires on wet surfaces. The results of these studies indicated that the braking friction coefficient decreased rapidly with increase in speed. At sufficiently high speeds the maximum braking friction coefficient was of the order of 0.1 or less.

In an attempt to improve braking friction on wet surfaces at high speeds, an exploratory investigation, reported herein, was undertaken on the tire treadmill of reference 1 to determine the effectiveness of two methods of clearing away water ahead of a tire. One method consisted of mounting a free-rolling or idling wheel ahead of a braking wheel (referred to as the tandem-wheel arrangement), and the other method consisted of directing an air jet on the water-covered surface ahead of a braking wheel. Tests were made with both smooth and diamond-treaded 3.00 × 7 tires (about 12 inches in diameter) on the braking wheel. Measurements of free-roll friction, maximum braking friction, and full-skid (locked wheel) friction were made at speeds from 26 to 93 feet per second. The depth of the water was 0.09 inch for all tests.

APPARATUS AND TESTS

Tandem-Wheel Arrangement

The tire treadmill used in the present tests was basically the same as that used in the investigation reported in reference 1. For the tandem-wheel arrangement the treadmill equipment was modified to allow an idling or free-rolling wheel to be mounted ahead of and independently of the braking wheel as shown in figures 1 and 2. Provision was made to permit the idling wheel to be raised off the belt for tests of the braking wheel alone.

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Smooth and diamond-treaded 3.00 × 7 tires (about 12 inches in diameter) were used on the braking wheel. The static vertical load on the braking wheel was 100 pounds and the tire inflation pressure was the recommended 13 pounds per square inch gage. The idling wheel had a 3.00 × 7 tire which was made smooth by grinding the tread material off a diamond-treaded tire. Measurements were made with static vertical loads on the idling wheel of 23, 63, and 103 pounds and the tire inflation pressure was 13 pounds per square inch gage.

The tests were made with a water depth of 0.09 inch over a range of speeds from 26 to 93 feet per second. At a given speed setting, measurements of free-roll and braking friction were made, by using the strain-gage balance described in reference 1, with and without the idling wheel in place.

Air-Jet Arrangement

For the tests with the air jets, the idling wheel was removed from the treadmill and two air supply tubes with inside diameters of 3/16 inch were installed. (See fig. 3.) The end of one of these tubes was fitted with about a $3\frac{1}{2}$-inch length of tubing having an inside diameter of 1/16 inch and the other was fitted with about a 2-inch length of tubing having an inside diameter of 1/8 inch. The ends of these smaller tubes were bent about 45° from the vertical (fig. 3) and were cut off parallel to and 1/8 inch above the belt surface. The openings were located about 1 tire diameter ahead of the axle of the braking wheel. A static-pressure orifice with connecting tubing was used in each of the air supply tubes for measuring the static pressure. Tests were made with the same tires and vertical load on the braking wheel as were used for the tandem-wheel arrangement. Tire friction measurements were made for a 0.09-inch depth of water over a speed range of 30 to 87 feet per second with static pressures from 0 to 103 pounds per square inch gage for both the 1/16-inch-diameter and 1/8-inch-diameter tubes. Each test was made with blowing from one jet only.

RESULTS AND DISCUSSION

Tandem-Wheel Arrangement

The results of the tests with the tandem-wheel arrangement are presented in figure 4 for the smooth tire and in figure 5 for the diamond-treaded tire for vertical loads on the idling wheel of 23, 63, and 103 pounds. Also shown in these figures are results obtained at the same time with the braking wheel alone; that is, with the idling wheel raised off the belt. Maximum braking friction coefficients, full-skid braking friction coefficients, free-roll friction coefficient, and free-roll wheel velocity are presented as functions of belt velocity. The friction coefficients were evaluated as described in reference 1.

With the idling wheel raised off the belt, the results are similar to those reported in reference 1 and show the rapid decrease in braking friction coefficient (maximum and full-skid), the increase in free-roll friction coefficient with increase in speed, and also the tire-planing phenomenon in which the wheel stops rotating at sufficiently high forward speeds. With the idling wheel ahead of the smooth tire (fig. 4), the maximum and full-skid braking friction coefficients still decreased with increase in speed but at a much reduced rate, and tire planing was eliminated up to the highest test speeds. At speeds at which the smooth tire would plane when operating alone, the use of the idling wheel increased the maximum braking coefficient by an increment of about 0.18 to 0.23, the amount of increase depending on the vertical load on the idling wheel. The full-skid braking friction coefficient, however, was increased only slightly at these speeds.

With the idling wheel ahead of the diamond-treaded tire (fig. 5), the maximum braking friction coefficient decreased rather slowly with increase in speed, and tire planing was not encountered up to the highest speed of the tests. At speeds at which tire planing would occur with the diamond-treaded tire operating alone, the idling wheel increased the maximum braking friction coefficient by an increment of about 0.17 to 0.22, the amount of increase depending on the vertical load on the idling wheel. There was little difference in the full-skid braking friction coefficient with and without the idling wheel in place.

For both the smooth and diamond-treaded tires, use of the idling wheel delayed the rise in free-roll friction coefficient with increase in speed and resulted in decrements in the free-roll friction coefficient of from 0.02 to 0.06, the amount of decrease depending on the tire and the vertical load on the wheel, at the highest test speeds.

It should be pointed out that the assessment of the advantage of using the tandem-wheel arrangement requires the determination of an effective braking friction coefficient based on the distribution of weight on the forward and rear wheels, with the assumption that both wheels will be braked. If the forward wheel is considered to have the braking-friction capability of the single-wheel arrangement and the rear wheel to have the capability of the braked (rear) wheel of the tandem-wheel arrangement, for a bogie gear with equal loads carried on the front and rear wheels and both wheels braked, the effective maximum braking friction coefficient at the highest speeds would be about 0.19 for a gear with smooth tires and 0.28 for a gear with diamond-treaded tires (front-wheel load 103 pounds, figs. 4 and 5). These values represent increments of 0.075 and 0.11 over the single-wheel value or the mean of two single-wheel values. However, for a weight distribution involving only 23 percent of the weight on the front wheel (front-wheel load 23 pounds, figs. 4 and 5), the values of the effective maximum braking friction coefficient are increased to 0.23 and 0.32 for the smooth and diamond-treaded tires, respectively, which are increments of about 0.16 over the single-wheel value.

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Air-Jet Arrangement

The results of the tests with the air-jet arrangement are presented for the 1/16- and 1/8-inch-diameter nozzles in figures 6 and 7 for the smooth tire and figures 8 and 9 for the diamond-treaded tire. Results are shown for air-jet total-pressure values of 0, 27, 48, 83, and 103 pounds per square inch. The results are presented in the same form as for the tandem-wheel arrangement.

Examination of the results in figures 6 to 9 indicates that for both the smooth and diamond-treaded tires, the use of blowing reduces the usual loss in maximum braking friction coefficient with increase in speed, and at the higher pressures used, the maximum braking friction coefficient becomes either constant or increases with increase in speed. In addition, with one exception, use of blowing eliminated tire planing up to the highest speed tested. The usual loss in the full-skid braking friction coefficient with increase in speed is improved only slightly by use of blowing. The rise in free-roll friction coefficient with increase in speed was delayed by blowing, and decrements in the free-roll friction coefficient of from 0.02 to 0.06, the amount of reduction depending on the air-jet pressure and the nozzle size, were obtained at the highest test speeds.

The effect of blowing on the maximum braking friction coefficient is summarized in figure 10, which gives the variation of maximum braking friction coefficient with air-jet pressure at belt speeds of 35, 60, and 80 feet per second for both the smooth and diamond-treaded tires and both 1/16- and 1/8-inch-diameter air nozzles. The results shown in figure 10 indicate that little or no increase in the maximum braking friction coefficient was obtained by means of blowing at the lowest speed, but an increment of about 0.07 was obtained at 60 feet per second and an increment of about 0.15 was obtained at 80 feet per second. In general, at the highest speed, the 1/8-inch-diameter nozzle gave somewhat larger increases in the maximum braking friction coefficient except at the highest air-jet pressure. For the 1/8-inch-diameter nozzle, the peak value of maximum braking friction coefficient for either tire was attained at air-jet pressures of approximately 50 pounds per square inch; further increases in pressure produced no significant increase in the friction coefficient. For the 1/16-inch-diameter nozzle, the peak values generally occurred at about the highest air-jet pressure of the tests (100 pounds per square inch).

CONCLUDING REMARKS

The results of an investigation of a tandem-wheel arrangement and an air-jet arrangement for improving braking friction on wet surfaces indicated that significant improvements were obtained in alleviating the usual loss in the maximum braking friction coefficient with increase in speed by both methods investigated. In addition, both methods generally eliminated tire planing up to the highest test speeds. For the tandem-wheel arrangement, increases in maximum braking friction coefficient ranging from increments of 0.18 to 0.23, the amount of increase depending on the vertical load on the idling wheel, were obtained at usual tire-planing speeds. The increases in maximum braking friction coefficient for a diamond-treaded tire were somewhat higher on the average than those for a smooth tire. For the air-jet configuration, an increment in maximum braking friction coefficient of about 0.15 was obtained with the highest blowing pressure at usual planing speeds for both 1/16- and 1/8-inch-diameter nozzles and both the smooth and diamond-treaded tires. Results of braking friction measurements with wheel locked showed only slight improvement in the value of the full-skid friction coefficient over the speed range investigated by either method. Decrements in the free-roll friction coefficient of 0.02 to 0.06 were obtained at the highest test speeds by both methods, the amount of reduction depending on the tread, vertical load, air-jet pressure, and nozzle size.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., March 24, 1960.

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3. Sawyer, Richard C., and Kolnick, Joseph J.: Tire-to-Surface Friction-Coefficient Measurements With a C-123B Airplane on Various Runway Surfaces. NASA TR R-20, 1959.

4. Trant, James P., Jr.: NACA Research on Friction Measurements. Proc. First Int. Skid Prevention Conf., Pt. I, Virginia Council of Highway Invest. and Res. (Charlottesville), Aug. 1959, pp. 297-308.

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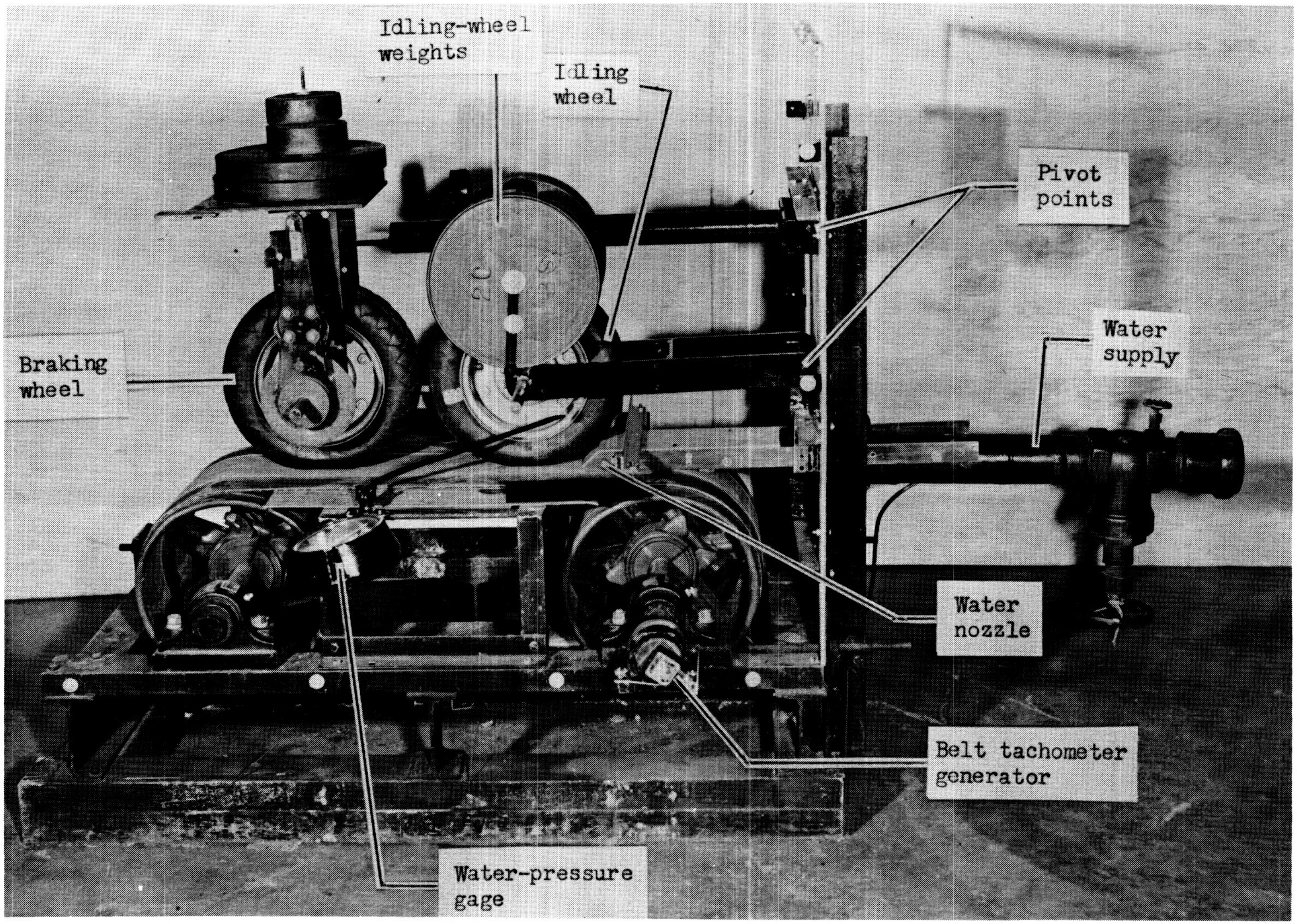

Figure 1.- Overall view of tire treadmill showing tandem-wheel arrangement. L-58-42.1

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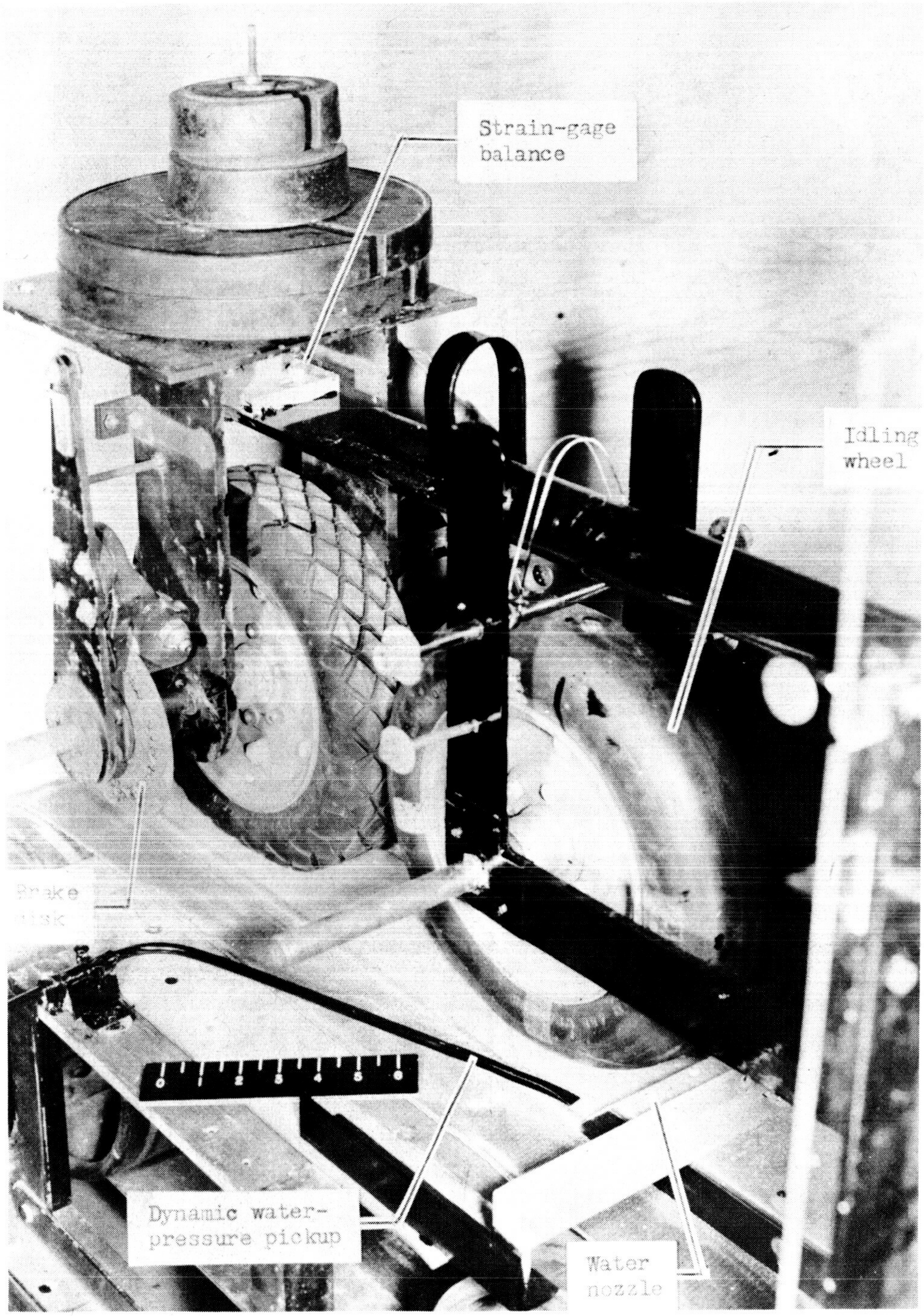

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Figure 2.- Closeup view of tire treadmill with tandem-wheel arrangement.

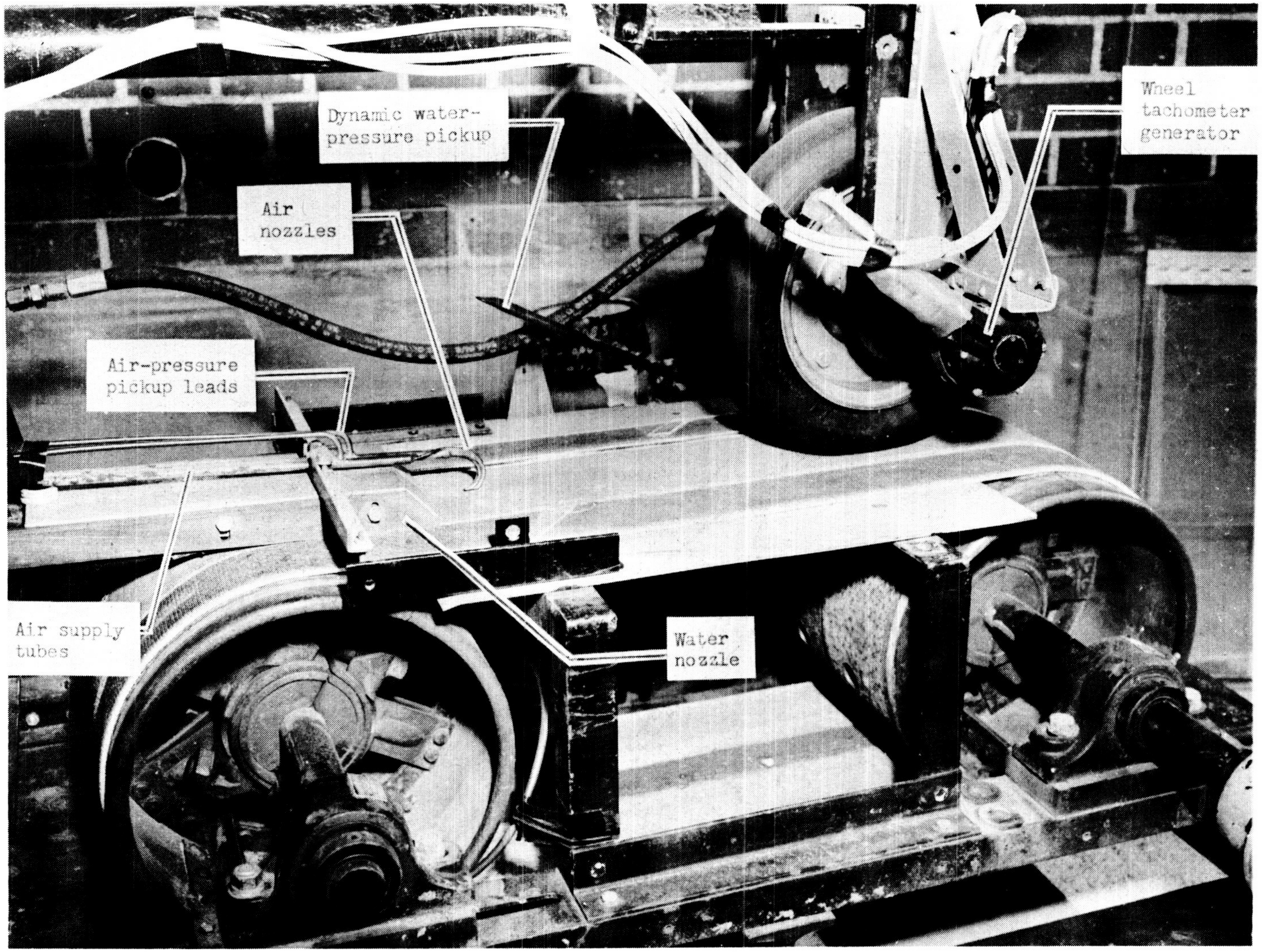
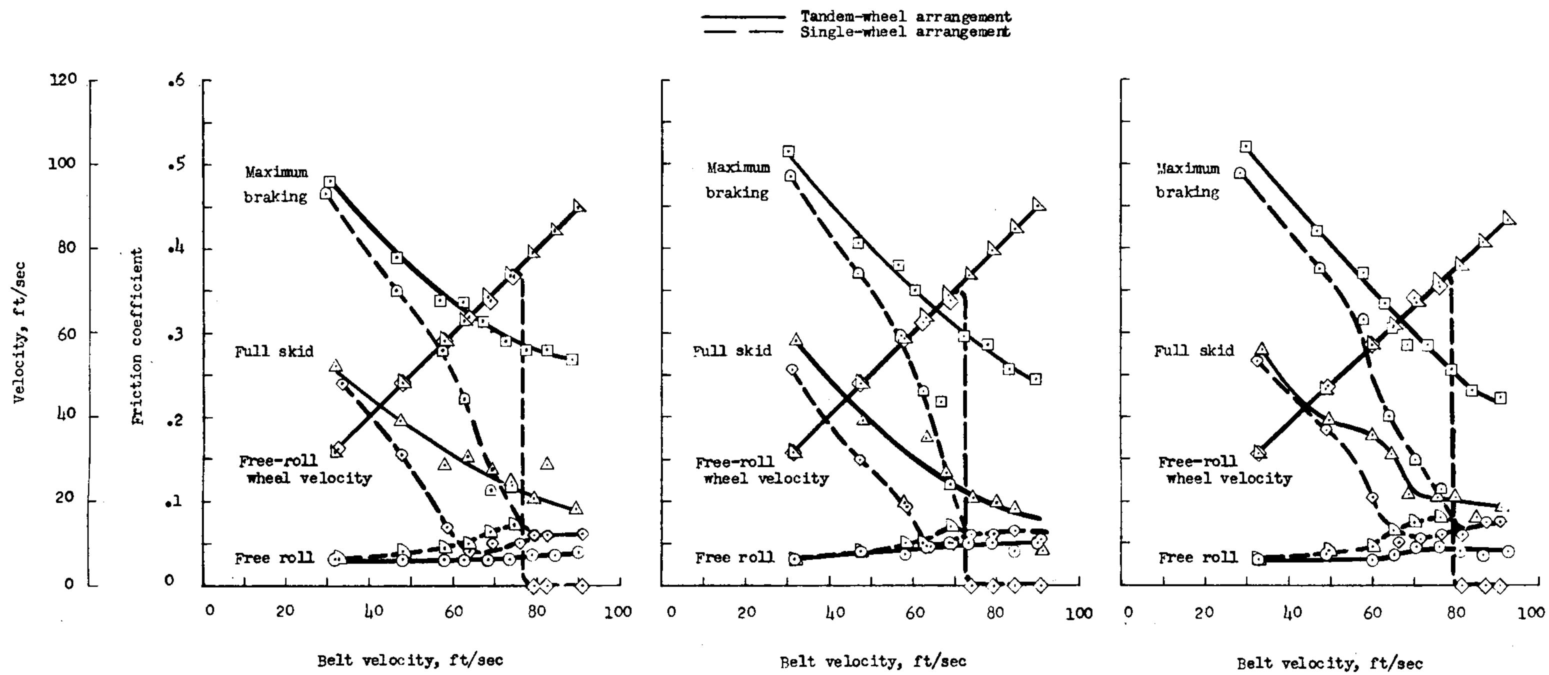


Figure 3.- Closeup view of tire treadmill showing air-jet arrangement. L-59-2218.1

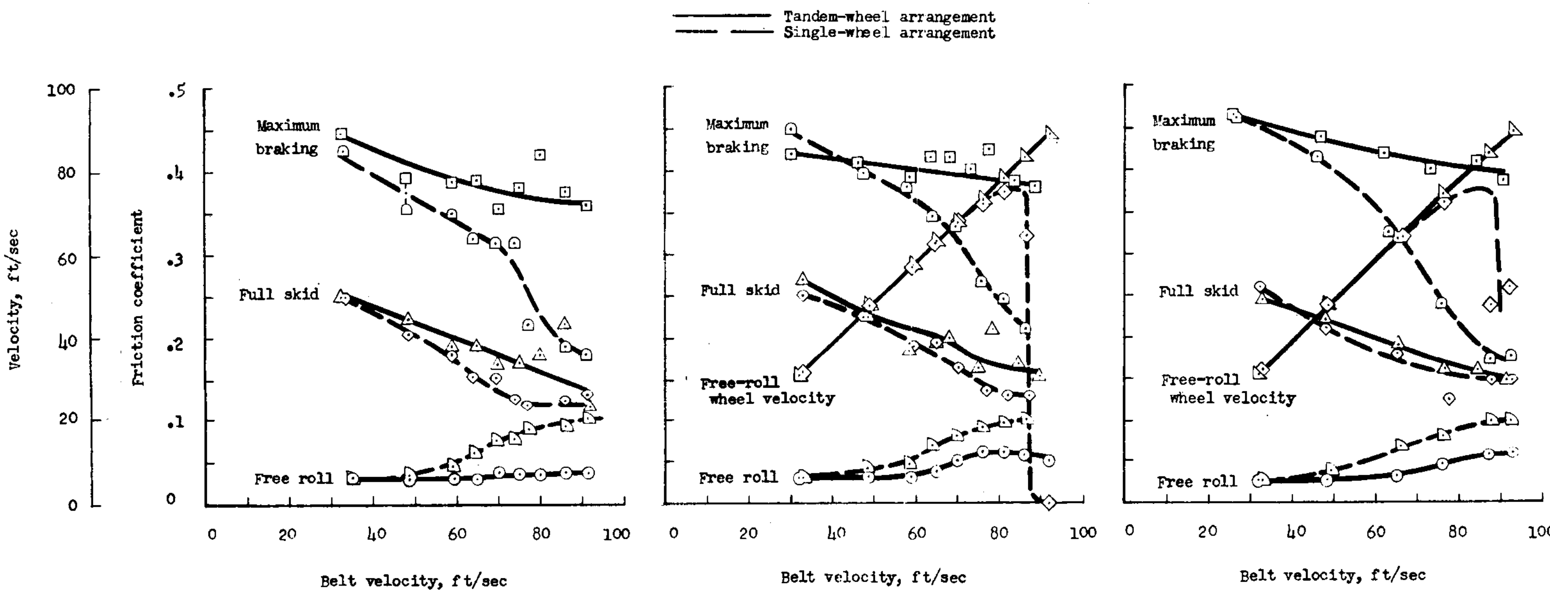


(a) Load on front wheel, 23 pounds.

(b) Load on front wheel, 63 pounds.

(c) Load on front wheel, 103 pounds.

Figure 4.- Variation of tire friction coefficient and wheel velocity with belt velocity. Single- and tandem-wheel arrangements; smooth tire.

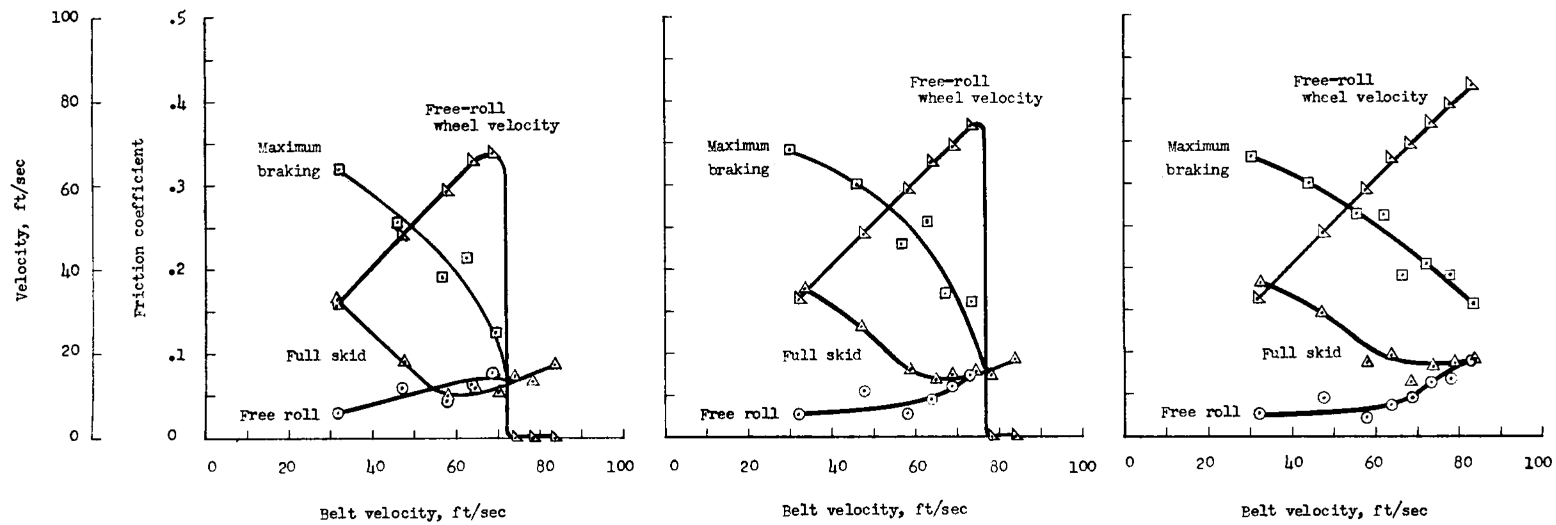


(a) Load on front wheel, 23 pounds.

(b) Load on front wheel, 63 pounds.

(c) Load on front wheel, 103 pounds.

Figure 5.- Variation of tire friction coefficient and wheel velocity with belt velocity. Single- and tandem-wheel arrangements; diamond-treaded tire.

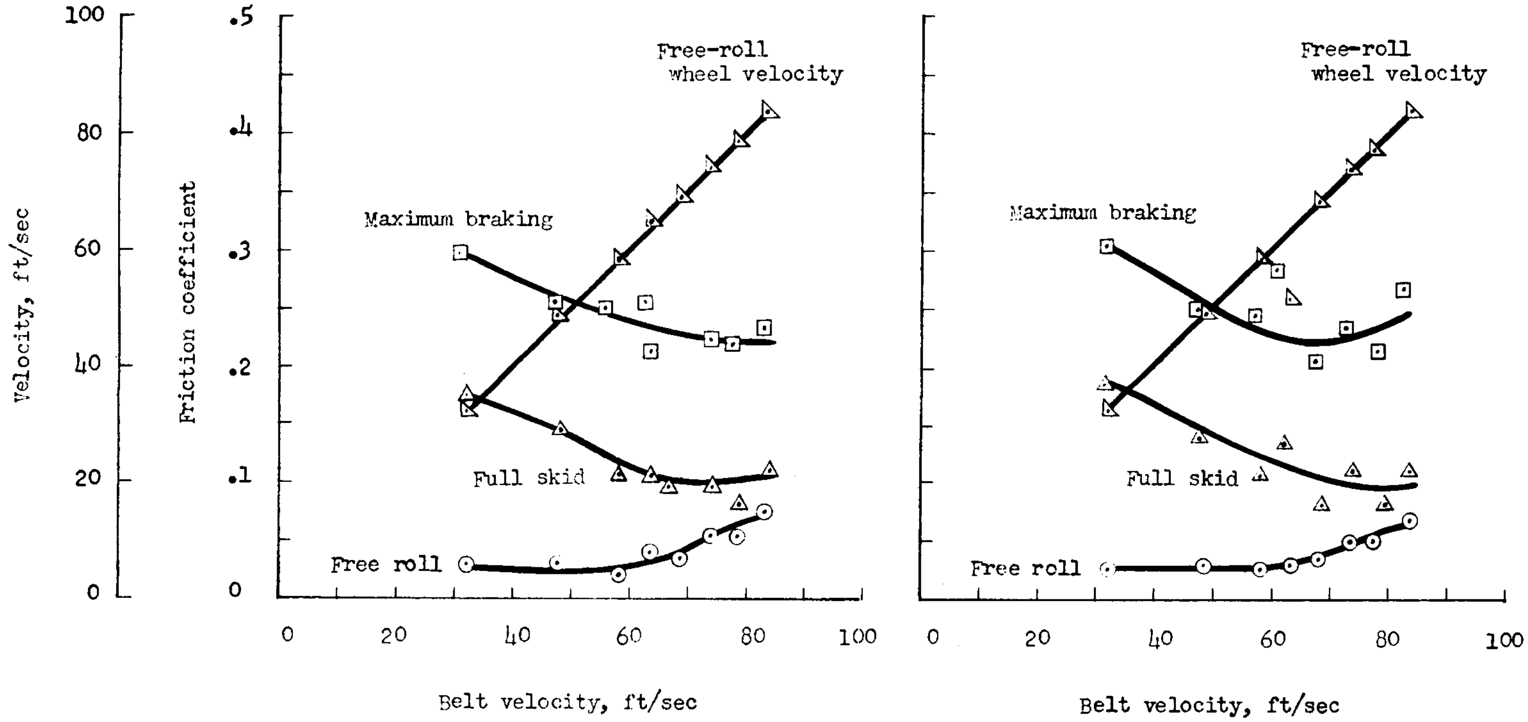


(a) Air-jet total pressure, 0 lb/sq in. gage.

(b) Air-jet total pressure, 27 lb/sq in. gage.

(c) Air-jet total pressure, 48 lb/sq in. gage.

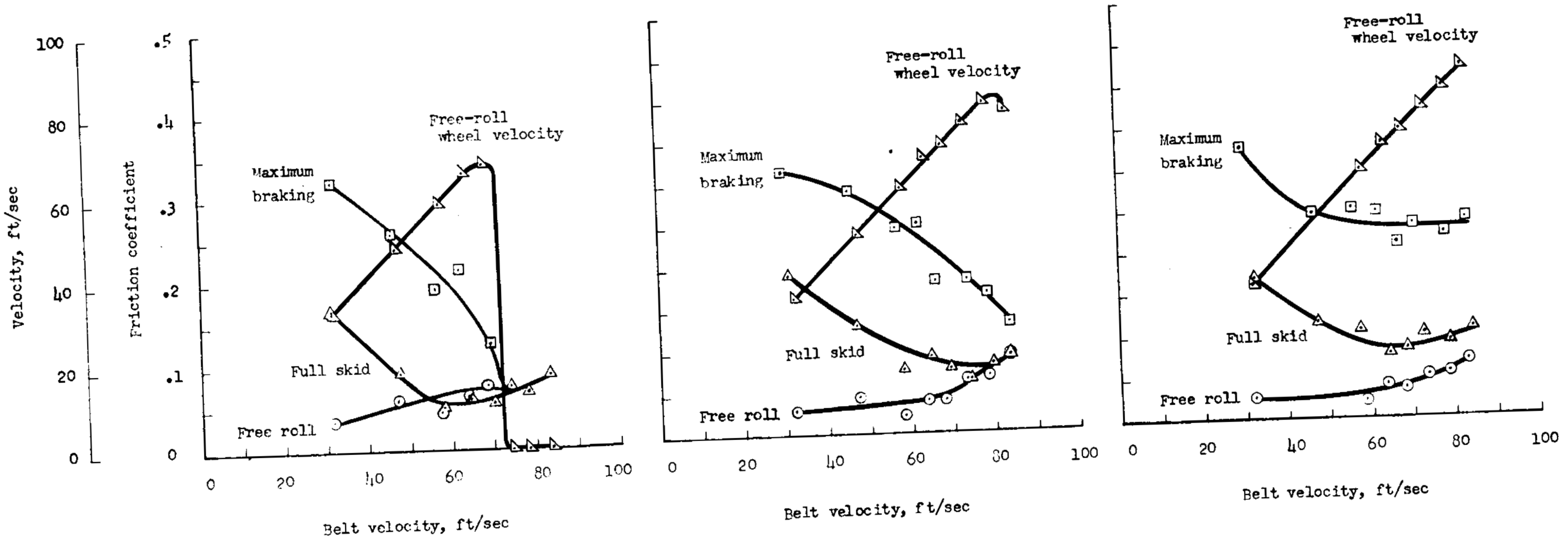
Figure 6.- Variation of tire friction coefficient and wheel velocity with belt velocity. Air-jet configuration; nozzle with 1/16-inch inside diameter; smooth tire.



(d) Air-jet total pressure, 83 lb/sq in. gage.

(e) Air-jet total pressure, 103 lb/sq in. gage.

Figure 6.- Concluded.

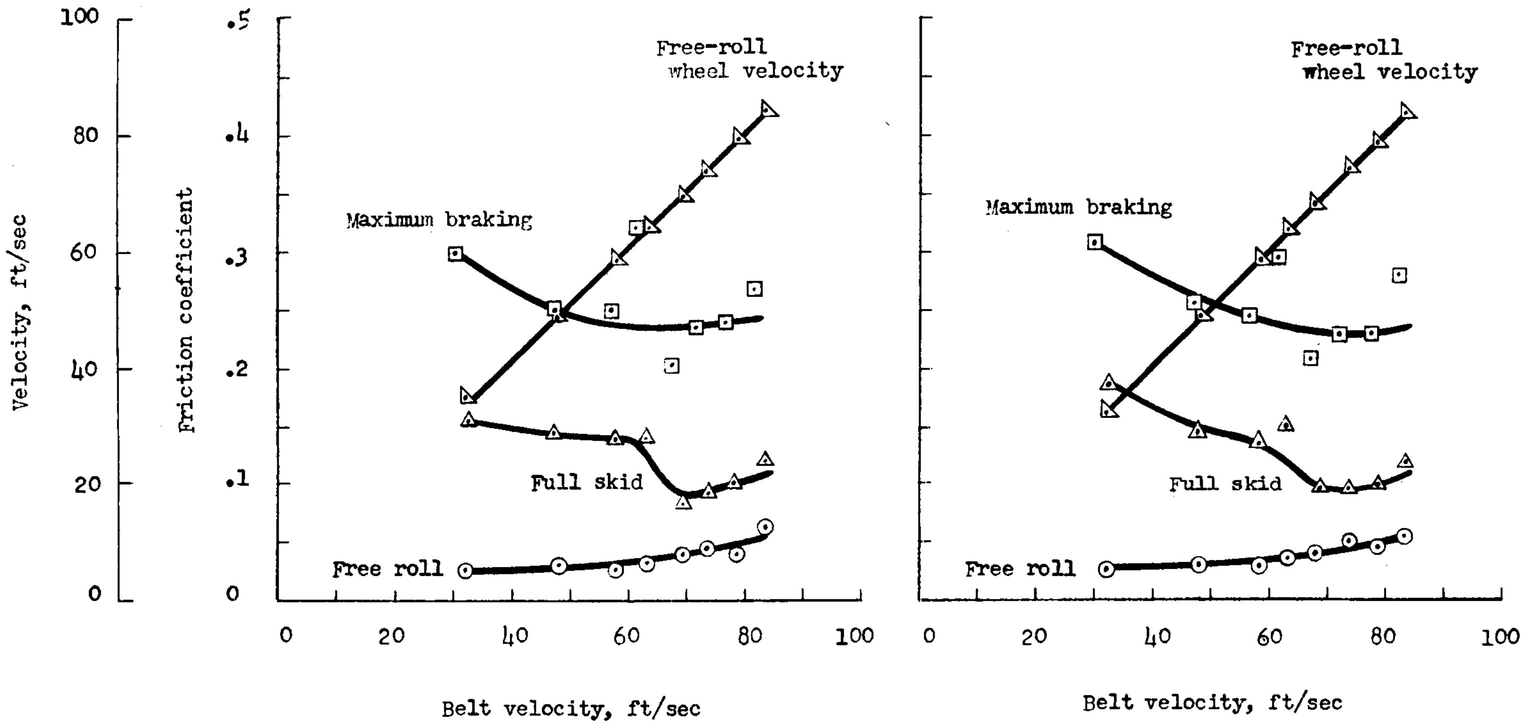


(a) Air-jet total pressure, 0 lb/sq in. gage.

(b) Air-jet total pressure, 27 lb/sq in. gage.

(c) Air-jet total pressure, 48 lb/sq in. gage.

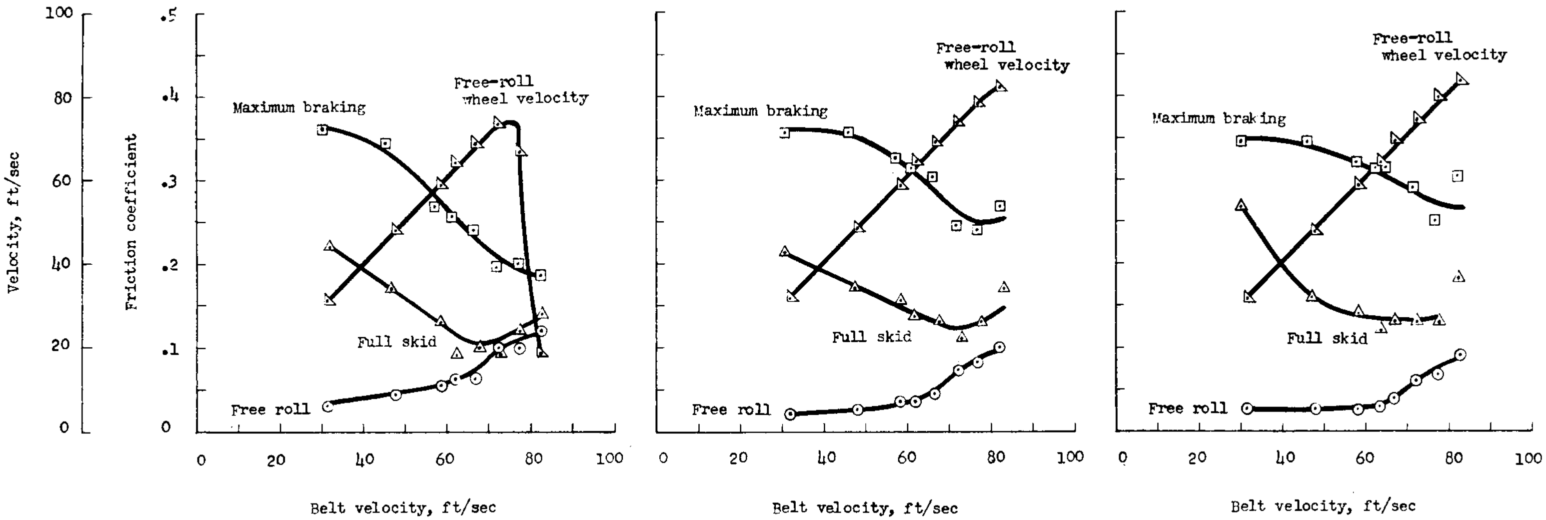
Figure 7.- Variation of tire friction coefficient and wheel velocity with belt velocity. Air-jet configuration; nozzle with 1/8-inch inside diameter; smooth tire.



(d) Air-jet total pressure, 83 lb/sq in. gage.

(e) Air-jet total pressure, 103 lb/sq in. gage.

Figure 7.- Concluded.

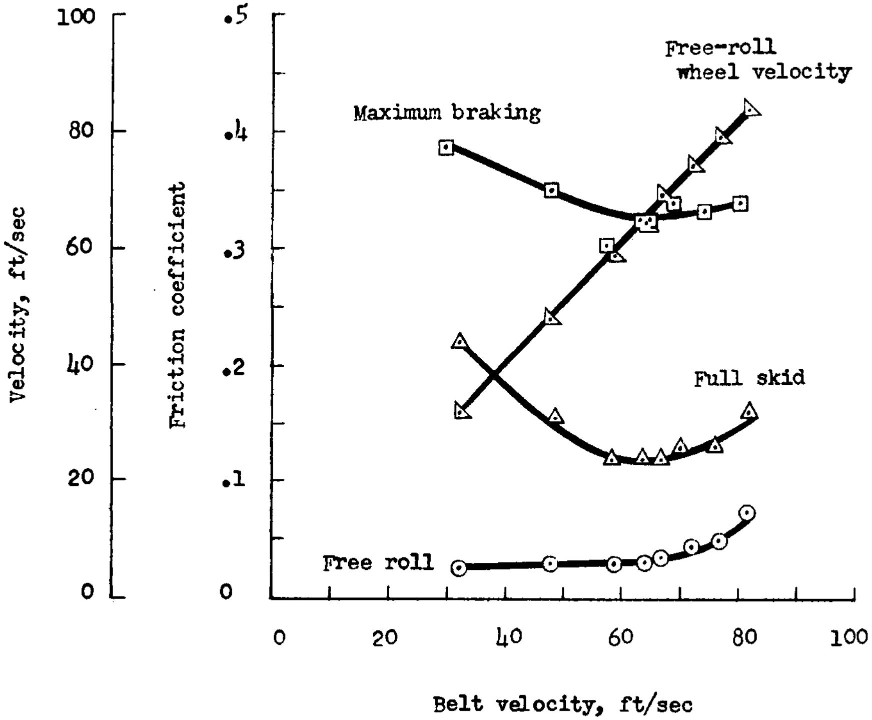


(a) Air-jet total pressure, 0 lb/sq in. gage.

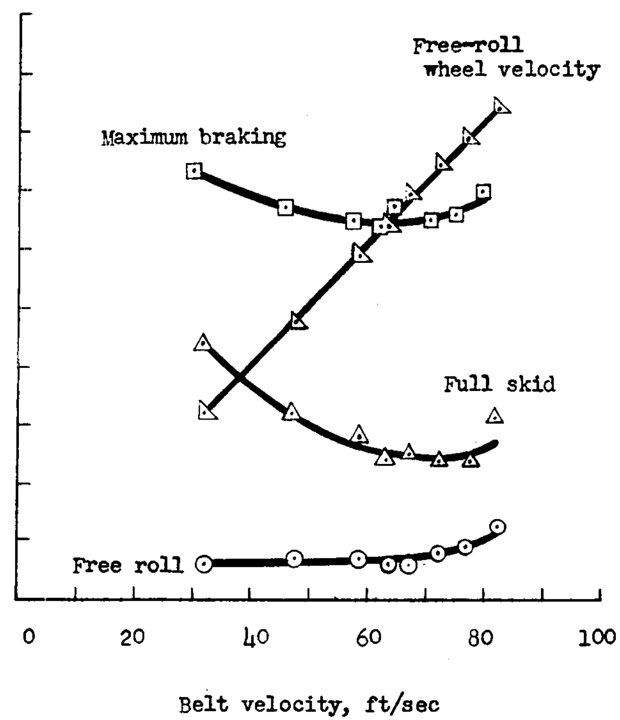
(b) Air-jet total pressure, 27 lb/sq in. gage.

(c) Air-jet total pressure, 48 lb/sq in. gage.

Figure 8.- Variation of tire friction coefficient and wheel velocity with belt velocity. Air-jet configuration; nozzle with 1/16-inch inside diameter; diamond-treaded tire.

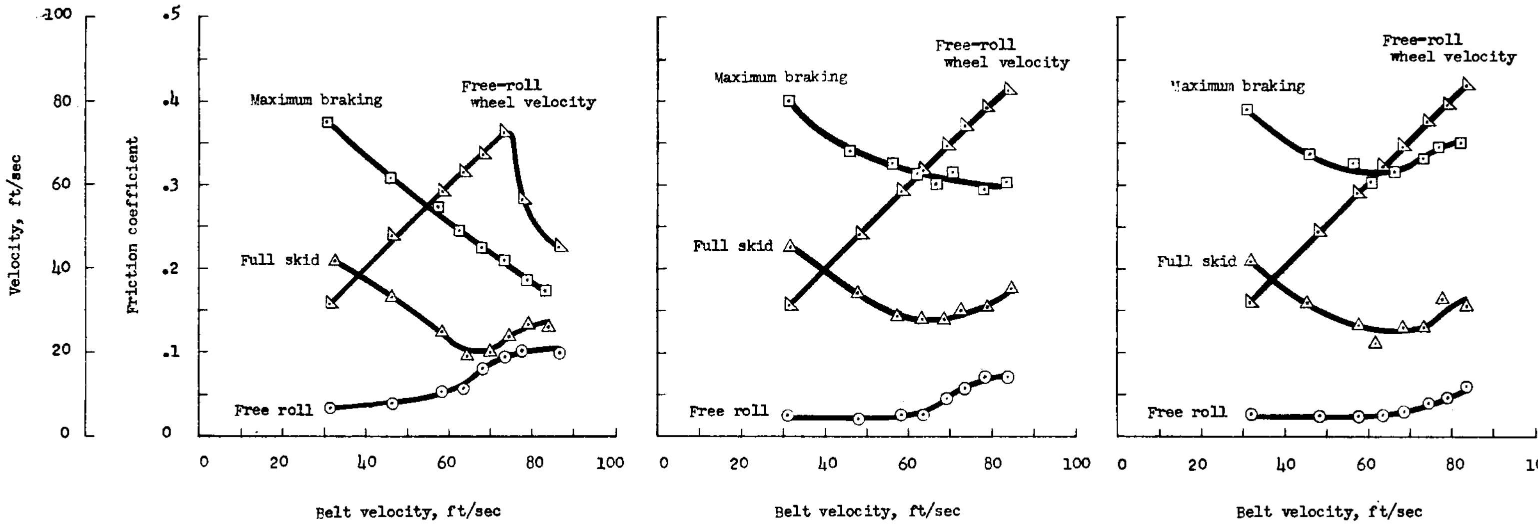


(d) Air-jet total pressure,
83 lb/sq in. gage.



(e) Air-jet total pressure,
103 lb/sq in. gage.

Figure 8.- Concluded.

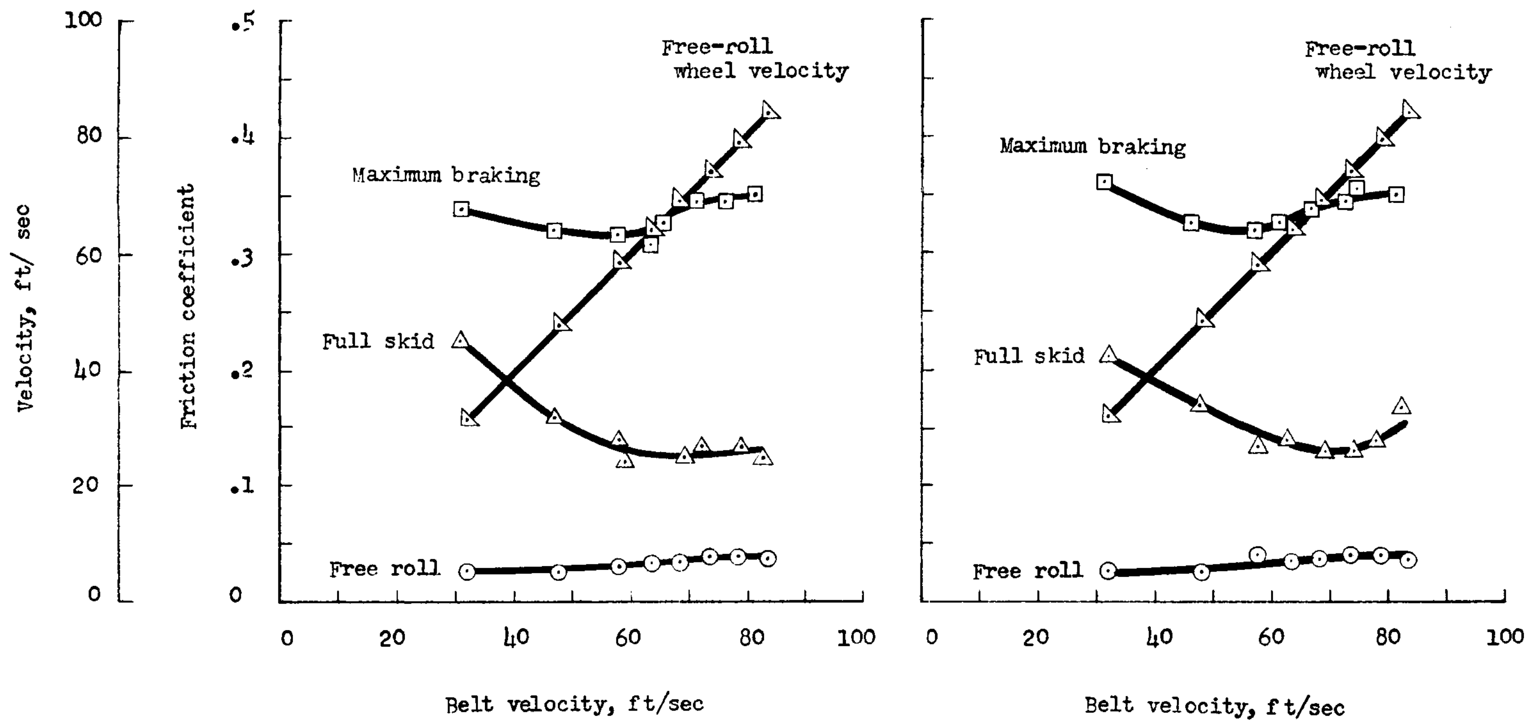


(a) Air-jet total pressure, 0 lb/sq in. gage.

(b) Air-jet total pressure, 27 lb/sq in. gage.

(c) Air-jet total pressure, 48 lb/sq in. gage.

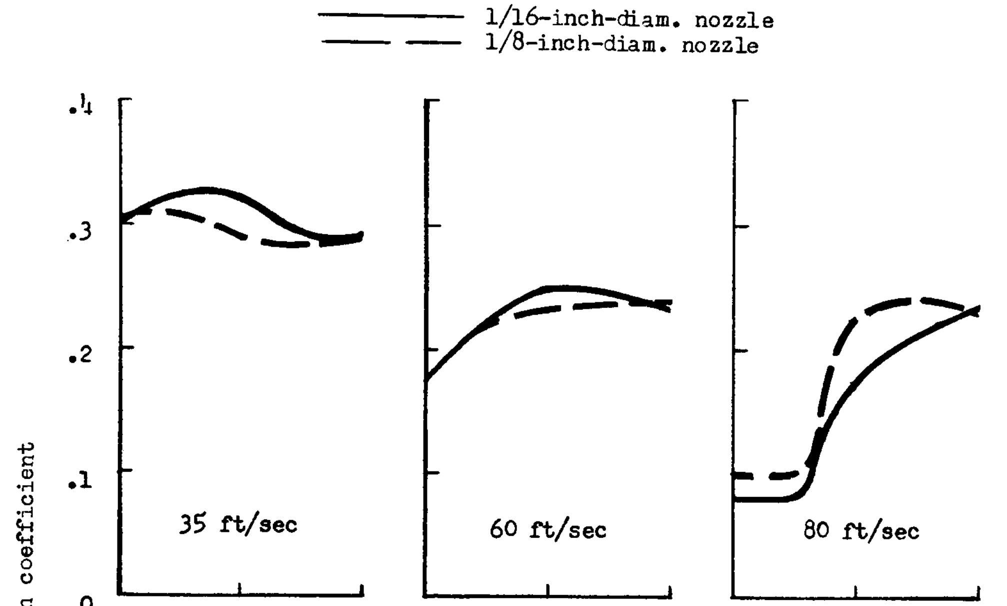
Figure 9.- Variation of tire friction coefficient and wheel velocity with belt velocity. Air-jet configuration; nozzle with 1/8-inch inside diameter; diamond-treaded tire.



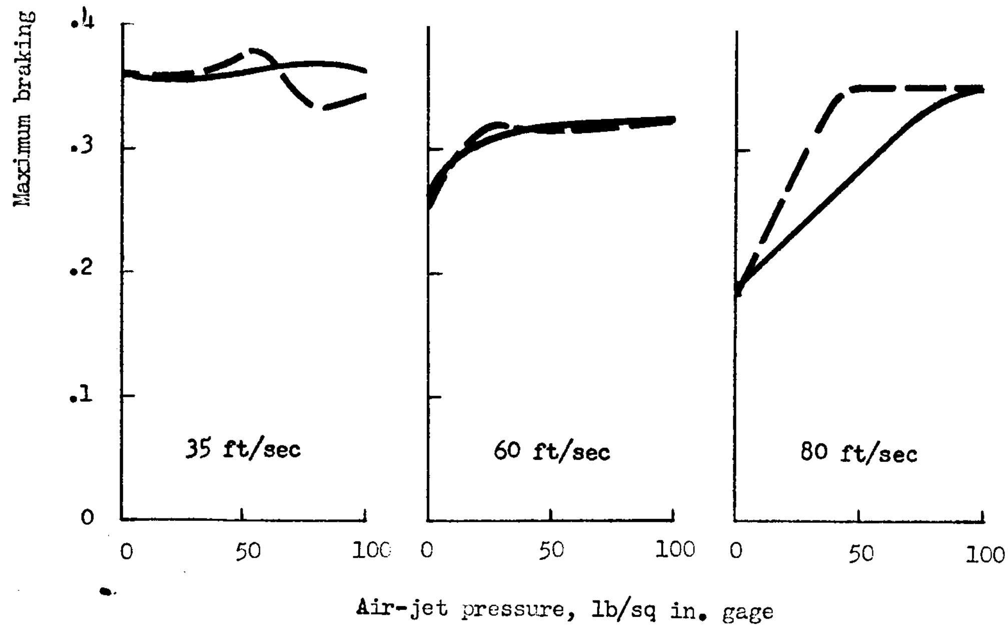
(d) Air-jet total pressure,
83 lb/sq in. gage.

(e) Air-jet total pressure,
103 lb/sq in. gage.

Figure 9.- Concluded.



(a) Smooth tire.



(b) Diamond-treaded tire.

Figure 10.- Effect of air-jet pressure on maximum braking friction coefficient at belt speeds of 35, 60, and 80 feet per second for both 1/16- and 1/8-inch-diameter nozzles. Smooth and diamond-treaded tires.

L-629